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Computed Tomographic Measurement of the Pulmonary Vein to Pulmonary Artery Ratio in Healthy Dogs: Influence of the Respiratory Phase and Contrast Study

건강한 개에서 폐정맥 대 폐동맥 비율의 컴퓨터 단층 촬영 측정: 호흡 주기 및 조영 검사의 영향

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Abstract

Computed Tomographic Measurement of the Pulmonary Vein to Pulmonary Artery Ratio in Healthy Dogs: Influence of the Respiratory Phase and Contrast Study

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In veterinary medicine, diagnosis of pulmonary hypertension relies on measuring tricuspid and pulmonic regurgitation velocity through Doppler echocardiography. Since, it is not always possible or accurate, several alternative echocardiographic indexes are proposed. Pulmonary vein to pulmonary artery ratio (PV/PA), a recently introduced echocardiographic index, which is about 1 in healthy dogs, has not been described in dogs using computed tomography (CT). The objectives of this cross-sectional, prospective study were to compare the PV/PA values obtained by thoracic CT in healthy dogs with those obtained by echocardiography determine if measurement of PV/PA via CT is repeatable and reproducible, and to evaluate the effect of the contrast injection and respiration phase on the measured PV/PA. Ten healthy dogs were anesthetized to undergo thoracic CT using four different protocols (pre-contrast inspiratory, pre-contrast expiratory, post-contrast inspiratory, post-contrast expiratory) and echocardiography. Pulmonary vein to pulmonary artery ratio was measured three times by three observers for each of the CT protocols and compared to echocardiographic measurements. The mean PV/PA obtained from the inspiratory CT protocol was close to 1 in both pre- and post-contrast, which was similar to the known echocardiographic value. Mean PV/PA values were significantly different between inspiratory and expiratory CT protocols ($P < 0.001$), where expiratory scans had higher PV/PA than inspiratory scans ($P < 0.001$). There was statistically significant linear relationship between pre- and post-contrast inspiratory CT protocols and echocardiography measuring PV/PA value ($r > 0.5$, $P < 0.05$). No linear relationship was observed between the PV/PA values measured by pre- and post-contrast expiratory CT scans and by echocardiography. In conclusion, PV/PA could be measured by thoracic CT in a similar way to the echocardiography. PV/PA values measured in the inspiratory CT protocol were similar to the value measured by echocardiography regardless of the contrast injection. However, since PV/PA values measured in the expiratory CT protocol were different from the previously known values, the respiratory phase should be considered when evaluating the pulmonary vascular size through CT.

Keywords: Cardiopulmonary disease, Echocardiography, Pulmonary hypertension, Index, Dog

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Introduction

Pulmonary hypertension (PH) can be categorized by pre-capillary PH and post-capillary PH. Pre-capillary PH is caused by heart worm disease, congenital shunts, chronic respiratory disease, whereas post-capillary PH is caused by left heart diseases such as myxomatous mitral valve degeneration and myocardial disease (Kellihan and Stepien, 2012). Pulmonary hypertension caused by these diseases will eventually negatively affect the cardiovascular system and increase the mortality (Kellihan and Stepien, 2012; Pyle et al., 2004).

The gold standard for diagnosing PH is known as right pulmonary artery catheterization (Hoeper et al., 2013). However, the procedure is rather invasive and may cause the risk in patients with PH (Ng et al., 1999). Therefore, pulmonary arterial pressure is indirectly estimated by measuring the tricuspid regurgitation (TR) and pulmonary regurgitation (PR) velocity through Doppler echocardiography. However, regurgitant flow may not be present or sufficient for measurement, and proper Doppler alignment is often difficult, which may lead to inaccurate measurements (Fisher et al., 2009; Rich et al., 2011). To compensate for these limitations, several indexes have been developed such as main pulmonary artery to aorta ratio and right pulmonary artery distensibility index which are non-invasive, simple, and not disturbed by Doppler alignment restrictions in PH detection (Serres et al., 2007; Visser et al., 2016). In the recent study, pulmonary vein to pulmonary artery ratio (PV/PA) was described by echocardiography in healthy dogs and dogs suffering from diseases such as myxomatous mitral valve degeneration and pre-capillary PH (Birettoni et al., 2016; Merveille et al., 2015; Roels et al., 2019).

To the authors knowledge, the morphological computed tomography (CT) analysis of the pulmonary blood vessels in healthy dogs and dogs with diseases such as pulmonary thromboembolism has been studied (Drees et al., 2011; Habing et al., 2011; Jung et al., 2010). However, a quantitative comparison between pulmonary veins (PV) and pulmonary arteries (PA) has not yet been performed on CT. Moreover, several lung diseases that can cause PH are common indications for thoracic CT, and since clinical symptoms such as cough, exercise intolerance, and syncope occurring in cardiopulmonary diseases are non-specific. Therefore, thoracic CT is indicated along with echocardiography to differentiate respiratory diseases. Therefore, it would be useful to determine the diagnostic utility of PV/PA measurement in the diagnosis of PH by thoracic CT. In addition, it is known that changes in blood flow and diameter occur in pulmonary blood vessels according to the respiratory cycle (Chiang et al., 1999; Patel et al., 2003; Ussavarungsi et al., 2014), while changes in various respiratory stages in PV/PA measurement have not been reported.

The purpose of this study was to compare the PV/PA values obtained by thoracic CT in healthy dogs with those obtained by echocardiography, and to evaluate the effect of contrast injection and respiratory phase on the PV/PA measurement.

Materials and Methods

1. Animals

Ten purpose-bred healthy beagles (eight intact females, two intact males) weighing 10 kg (range: 7.5 kg – 11 kg) were included in the study. No significant findings were observed in physical examination, thoracic radiography and echocardiography prior to anesthesia. All protocols were approved by Seoul National University institution's animal care and use committee (SNU-210818-3).

2. Computed tomographic examination

Acepromazine (0.02 mg/kg IV, Sedaject®, SamuMedian Co., Seoul, South Korea) was administered intravenously as a premedication. For the induction, alfaxalone (2.0 mg/kg IV, Alfaxan®, Jurox Pty Ltd., Rutherford, NSW, Australia) was administered intravenously and intubation was performed for inhalation anesthesia. Isoflurane (Ifran®, Hana Pharm., Seoul, South Korea) was used for maintenance and 100% FiO2 was provided. Monitoring of non-invasive blood pressure, oxygen saturation, heart rate, and end-tidal carbon dioxide were proceeded during the anesthesia.

All CT scans were performed using the 64-slice scanner (Aquillion 64™, Toshiba Medical Systems, Tochigi, Japan) by a veterinarian with diagnostic imaging expertise. All dogs were positioned with sternal recumbency, and helical transverse images were acquired using the following parameters: 1.0 mm slice thickness, 120 kVp, 200 mAs, 512 x 512 matrix, 0.75 s/rotation, and a spiral pitch factor of 1.484. Both pre- and post-contrast CT scans were performed for all dogs at positive pressure breath hold (inspiratory phase) and at the end of expiration (expiratory phase). Initial CT scans were performed in the inspiratory state using a positive pressure breath hold of 15 cmH_2O. Breath hold was limited to not more than 60 seconds. Without any positive pressure, end-tidal scans were then obtained. Then, 2 ml/kg of iodinated contrast medium (Omnipaque™ 300, GE Healthcare, Oslo, Norway) was injected through a preloaded intravenous catheter at a rate of 2 ml/s using an injector (Stellant™, Medrad Inc., PA, USA). After the administration, CT scans were performed in the inspiratory and expiratory phases in the same manner.

3. Echocardiographic examination

CT scans and echocardiographic examinations were performed on the same day in all dogs. After CT scan, echocardiography was performed on each dog under anesthesia. All echocardiographic examinations were performed using a sector transducer (2 - 9 MHz, Arietta 850, Hitachi Ltd., Tokyo, Japan) by a veterinarian with diagnostic imaging expertise. The dog was placed on the right recumbency and the electrocardiographic lead was connected. The presence of TR and PR was confirmed in the standard right parasternal long axis and short axis view. Then, as previously described (Birettoni et al., 2016; Roels et al., 2019), the optimized right parasternal long axis view for measurement of the PV and PA was obtained. For obtaining the optimized right parasternal long axis view, the transducer was moved apically and angled dorso-cranially visualizing the right ostium of the PV longitudinally and the right PA transversely (Fig. 1). All images were acquired by one veterinarian (J.L).

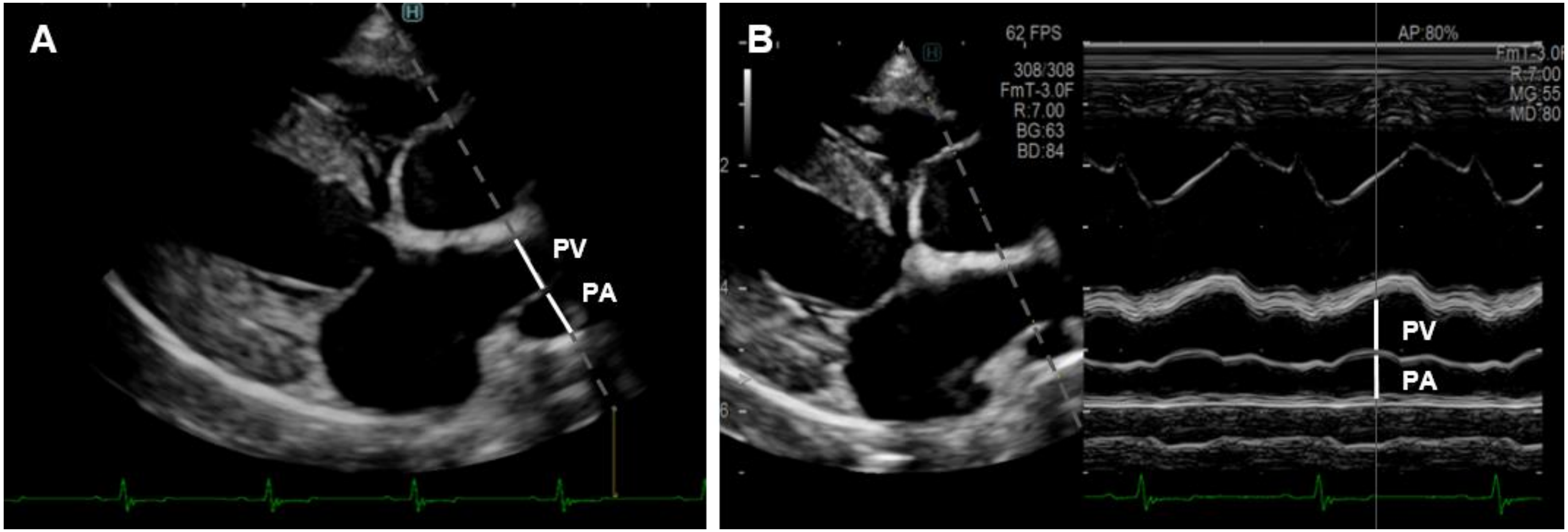

Figure 1. Measurement of pulmonary vein (PV) and pulmonary artery (PA) in two-dimensional (A) and time-motion mode (B) echocardiographs using optimized right parasternal long axis view. The dotted lines show the path transecting the vessels for two-dimensional measurement and time-motion mode acquisition.

4. Computed tomographic and echocardiographic measurements of pulmonary vein and pulmonary artery

The anonymized data were assigned to the three other veterinarians with diagnostic imaging expertise (J.L, J.C, L.B) and independently evaluated using a DICOM viewer software (RadiAnt DICOM Viewer, version 5.6.9, free evaluation edition, Medixant, Poznan, Poland). Measurements of the diameters of PV and PA were performed using two-dimensional (2D) and time-motion mode (MM) echocardiographs. As previously described (Roels et al., 2019), the diameters of both vessels were obtained on the line perpendicular to the long axis of PV and bisecting the PA (Fig. 1). To obtain the PV/PA, the average of at least three PV and PA diameter measurements were obtained from both 2D and MM. Both blood vessel diameters were measured by the inner edge to inner edge method at the timing of the end of the T wave. The diameter of aorta (AO) was measured in right parasternal short axis view with inner edge to inner edge method immediately after the aortic valve closure as previously described to calculate PV/AO and PA/AO ratios for normalizing PV and PA diameter which are the weight-dependent variables (Georgiev et al., 2013; Merveille et al., 2015). Similar to echocardiography, PV/PA was obtained based on the sagittal images after multiplanar reconstruction of CT images. In the image showing the right PV longitudinally before entering the left atrium through the right ostium and the right PA transversely in the dorsal position of the right PV, the diameter of each vessel was measured on the line perpendicular to the long axis of PV and intersecting the maximum diameter of PA (Fig. 2). Subsequently, the widest short axis diameter of

AO was measured on the transverse plane. In pre- and post-contrast CT images, the diameter of blood vessels was measured, including the outer wall when possible. Measurements of PV/PA and AO were performed three times to evaluate intra-observer changes. To investigate inter-observer variability, two additional observers (J.C., L.B.) performed the same measurements according to the instructions provided.

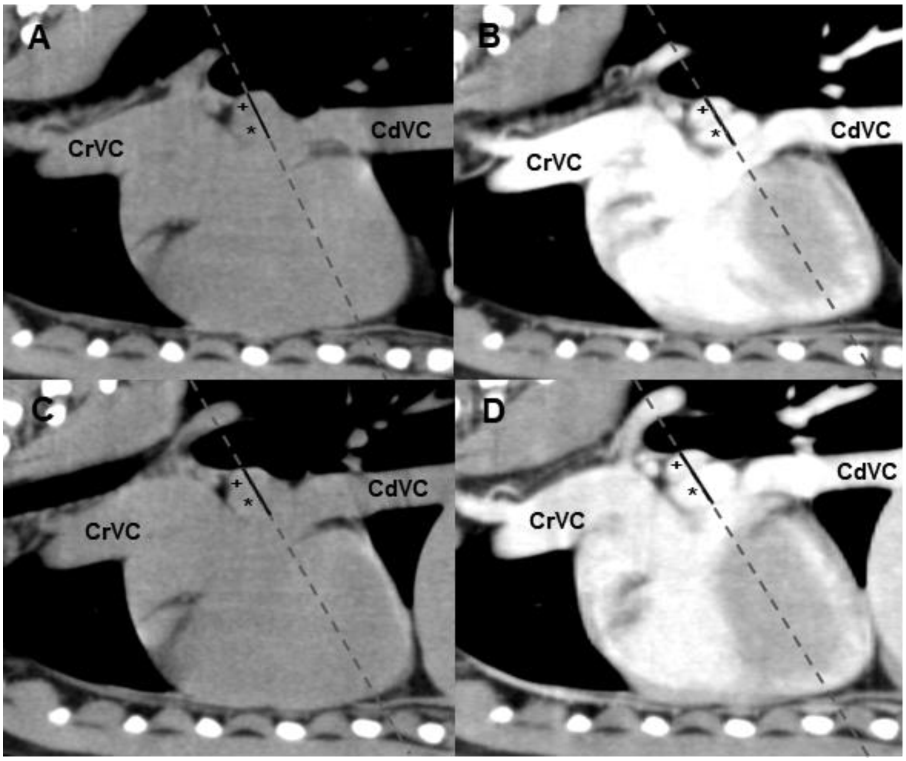

Figure 2. Sagittal computed tomographic images to measure pulmonary vein (PV) (*) to pulmonary artery (PA) (+) diameter ratio in each of four scans: (A) pre-contrast inspiratory scan, (B) post-contrast inspiratory scan, (C) pre-contrast expiratory scan, (D) post-contrast expiratory scan. The dotted lines show the path transecting the vessels for the measurement. CdVC, caudal vena cava.; CrVC, cranial vena cava

5. Statistical analysis

All statistical analyses were done by a veterinarian with diagnostic imaging expertise using statistical software (SPSS statistical program, IBM SPSS Statistics 25, IBM Corporation, NY). A P-value of less than 0.05 was considered to be significant. All the variables were assessed with the Shapiro-Wilk test for normality. In order to graphically display the variability between the observers according to the CT scan protocols, the measurement values taken by each observer within each CT scan protocol were averaged and displayed on a box-and-whisker plot. Using the average of all three observers, the difference in PV/PA values between CT protocols was determined by the Kruskal-Wallis test, because some variables did not follow a normal distribution. Afterwards, t-test or Mann-Whitney U test according to the normality was used for post hoc pairwise comparisons. The strength of the relationship between PV/PA values obtained from each CT protocol and echocardiography was investigated using Pearson or Spearman correlation according to normality. For comparison between each CT measurement and echocardiography, the t-test or Mann-Whitney U test was used according to the normality. In addition, the variability of intra- and inter-observer measurement associated with vascular measurements was assessed. To determine the intra- and inter-observer variability of each variable (PV/PA, PV/AO, and PA/AO), the intra- and inter-observer coefficient of variation for each study in each CT protocol and echocardiographic measurement was calculated. If the coefficient of variation was less than 10 %, it was considered as good agreement.

Results

Pulmonary arterial pressure could not be measured because TR and PR were not presented in all dogs in the study. Pulmonary hypertension was considered to be absent based on physical examination, thoracic radiograph, and echocardiography.

Most of the measurements of PV and PA diameters on CT images were made in the slice where the cranial and caudal vena cava shown together. Pulmonary vein diameter was measured at the position before entering the left atrium after the fusion of right middle and cranial lobar PVs (Fig. 2). Subjectively, the trunk formed after the confluence of the two blood vessels increased in width but similar or slightly increased in height in the sagittal plane. Technically, in many cases, the boundary between PV and PA was not clearly identified in the pre-contrast scan (Fig. 2A, C). Subsequently, the measurement was made by to the difference in the shape of the two vessels. Also, the fat provided distinction between PV and caudal vena cava in most cases, but in some pre-contrast scans, it was difficult to distinguish them.

The average and range of PV/PA values measured by each observer within each CT protocol are shown in Fig. 3. In order to investigate the effect of the CT protocol on PV/PA, each protocol was compared by the average of the measured values for all three observers (Table 1). There was a significant difference between the four methods ($P < 0.001$), and post-hoc analysis showed that the expiratory protocol had a significantly larger PV/PA value than the inspiratory protocol both in the pre- and post-contrast scan ($P < 0.001$). This difference is thought to be due to an increase in the PV size and a decrease in the PA size, as recognized by the changes in PV/AO and PA/AO (Table 2). There was no significant difference between the pre-contrast and post-contrast protocols of inspiratory ($P = 0.739$) and expiratory phase ($P = 0.971$).

The mean PV/PA measured by all three observers with 2D and MM echocardiography was 1.065 ± 0.050 (SD) and 1.078 ± 0.269 (SD), respectively. The mean PV/PA measured by all three observers using each CT protocol and echocardiography were compared (Table 3). A linear relationship was observed between the PV/PA values measured by pre- and post-contrast inspiratory CT scans and values that measured by echocardiography ($r > 0.5$, $p < 0.05$). No linear relationship was observed between the PV/PA values measured by pre- and post-contrast expiratory CT scans and values measured by echocardiography. Apart from the linear relationship, when comparing the mean PV/PA values measured by each CT protocol and echocardiography, the PV/PA values measured by pre- and post-contrast expiratory CT scans were significantly larger than values that measured by echocardiography ($P < 0.001$). There was no significant difference between the PV/PA values determined by inspiratory CT scans of both pre- and post-contrast and that of echocardiography ($P > 0.05$).

In each CT protocol and echocardiographic measurement method, the average inter-observer coefficient of variation for the variables (PV/PA, PV/AO, and PA/AO) was 2.2-11.0 % and the average intra-observer coefficient of variation was 0.6-5.2 %, which mostly showed good inter- and intra-observer agreement.

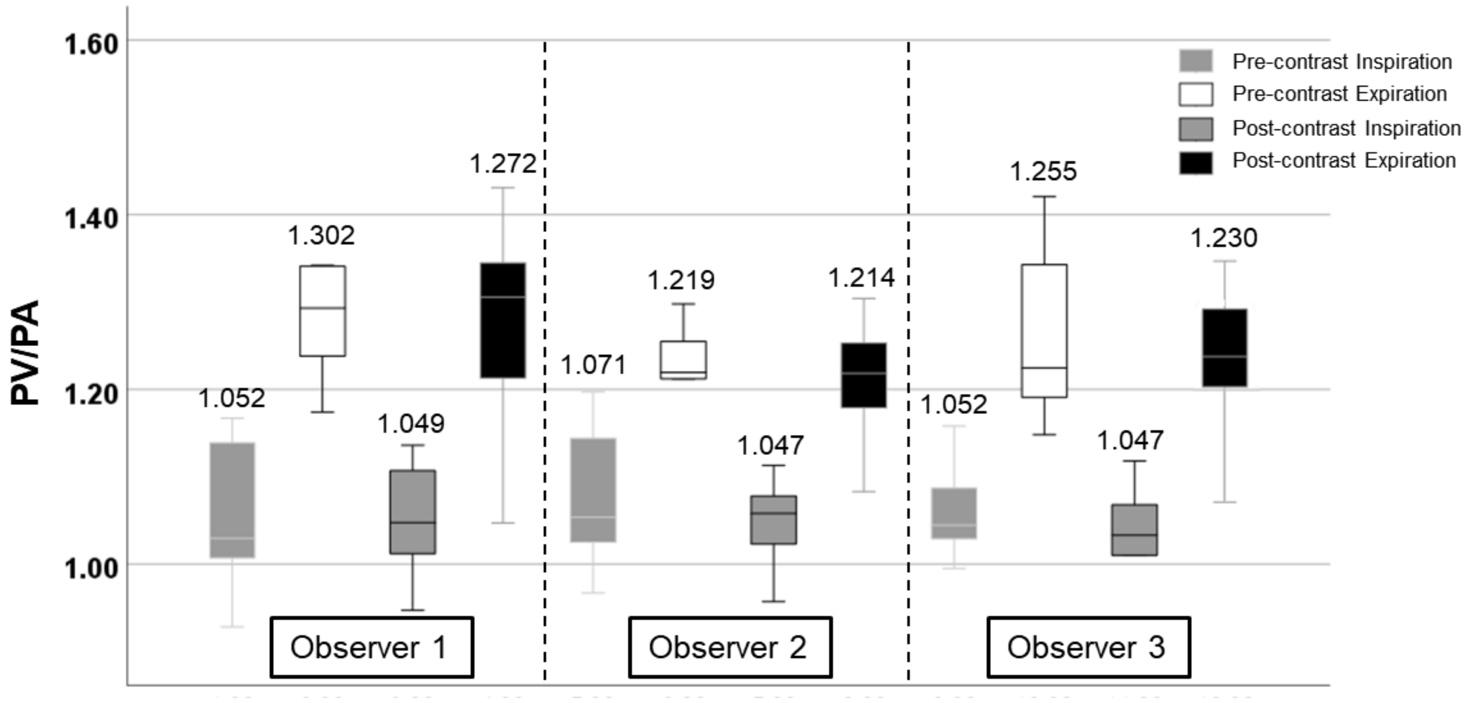

Figure 3. Box plots of the pulmonary vein to pulmonary artery ratio (PV/PA) measured by each of the observers for each of the computed tomographic protocols. The average of each observer is included above each box.

Table 1. The mean pulmonary vein to pulmonary artery ratio (PV/PA) measured by three observers within each of the computed tomographic protocols.

PV/PA	Pre-contrast Inspiration	Pre-contrast Expiration	Post-contrast Inspiration	Post-contrast Expiration
Mean	1.058	1.259	1.040	1.239
SD	0.072	0.094	0.053	0.066

SD, standard deviation

Table 2. The mean pulmonary vein to aorta ratio (PV/AO), pulmonary artery to aorta ratio (PA/AO) measured by three observers within each of the computed tomographic protocols.

Measurements		Pre-contrast Inspiration	Pre-contrast Expiration	Post-contrast Inspiration	Post-contrast Expiration
PV/AO	**Mean**	0.474	0.539	0.497	0.536
	SD	0.037	0.070	0.069	0.062
PA/AO	**Mean**	0.449	0.428	0.477	0.432
	SD	0.035	0.030	0.056	0.036

SD, standard deviation

Table 3. Correlation of pulmonary vein to pulmonary artery ratio (PV/PA) between computed tomographic (CT) protocols and two-dimensional (2D) and time-motion mode (MM) echocardiography (ECHO).

ECHO \ CT	Pre-contrast Inspiration	Pre-contrast Expiration	Post-contrast Inspiration	Post-contrast Expiration
2D	0.727 (0.017)	0.010 (0.978)	0.634 (0.049)	0.179 (0.621)
MM	0.690 (0.027)	0.075 (0.837)	0.718 (0.019)	0.381 (0.271)

Coefficient of correlation (P value)

Discussion

In this study, PV/PA could be evaluated by thoracic CT in a method similar to echocardiography, and that PV/PA values measured in inspiratory phase were similar to those obtained in echocardiography.

According to the previous studies of PV anatomy in dogs, PVs anastomose before entering left atrium to form cone-shaped trunks that each connect to three ostia (cranial left ostium, caudodorsal ostium, and right ostium). The right ostium of PV is formed by the fusion of the right middle and cranial lobar PVs, and is separated from the other two ostia by PA which runs dorsally (Brewer et al., 2012; Gómez et al., 2012; Verheule et al., 2002). In this study, all measurements of PV in CT and echocardiography were performed at the anastomosis of the blood vessels continued to the right ostia. However, the sectional plane obtained by CT where measuring the vessel diameter is parallel to the long axis of the dog in the gantry, which is different from the axis of the heart as imaged in echocardiography. Moreover, since the measurement is not performed in a perfect circular structure, the difference in the measurement may be caused by the difference in angle.

In previous studies, reference intervals of healthy dogs were reported as a mean PV/PA of 1 with excellent intra- and inter-observer reproducibility on 2D and MM echocardiography (Birettoni et al., 2016; Merveille et al., 2015). The mean PV/PA obtained from inspiratory CT protocol was close to 1 in both of pre- and post-contrast, which was similar to previous studies. Whereas, PV/PA values obtained from expiratory CT protocols were significantly larger than those of the inspiratory CT protocols. This represents that there is an effect of the respiratory phase on the PV/PA measurement, and the respiratory phase should be considered when measuring PV/PA via CT. The increased PV/PA value in expiratory CT protocols is considered to be due to the increased PV size and decreased PA size through the changes in PV/AO and PA/AO between the protocols. The size of the vessel depends on the blood flow, intravascular hydrostatic pressure, and the vascular compliance. Pulmonary veins are more compliant and generally enlarged with left ventricular failure or increased pulmonary blood flow (Porres et al., 2013). Pulmonary arteries enlarge principally due to the increases in pulmonary blood flow and pulmonary artery pressure (Moore et al., 1988). Cyclic modifications of the heart's hemodynamics during respiration, including changes in intrathoracic pressure that occur during inspiration and expiration, cause fluctuations in blood flow in the heart (Ginghina et al., 2009). In normal respiration, intrathoracic and intrapericardial pressures decrease with inspiration, which causes an increase in right ventricular filling and stroke volume, with a compensatory decrease in left ventricular filling and stroke volume. With expiration, intrathoracic and intrapericardial pressures increase and result in opposite change (Ginghina et al., 2009; Morgan et al., 1966; Morgan et al., 1966). However, inspiratory CT scans were performed using positive pressure breath hold and end-tidal CT scans were performed without any positive pressure in this study. With positive pressure ventilation, as opposed to normal respiration, intrathoracic pressure increases during inspiration resulting in decrease of venous return, right ventricular cardiac output, and pulmonary blood flow (Guarracino et al., 2016; Scharf et al., 1977). In addition, interstitial pressure also increases, compressing the pulmonary capillary and impeding flow, leading to fluid retention in the interstitium. During expiration, intrathoracic pressure decreases back, increasing capillary flow and venous return (Soni and Williams, 2008). Moreover, changes in airway pressure during positive pressure ventilation cause changes in transmural pressure of the pulmonary vessels, which is related to the vessel diameter (Grübler et al., 2017). When the lungs inflate, the pressure surrounding the extra-alveolar vessels decreases due to the radial traction of the alveolar wall and the diameter of the blood vessels increases (Weiss, 1991). In positive pressure ventilation, the PA diameter increases as the airway pressure increases (Choen et al., 2019). These reasons may produce significantly different mean PV/PA in expiratory CT protocols compared to the inspiratory CT protocols due to increased PV diameter and decreased PA diameter during expiration.

The mean value of PV/PA measured by echocardiography was close to 1 in both 2D and MM, as in previous studies. A moderate to strong correlation was found between PV/PA measurements of pre- and post-contrast inspiratory CT protocol and echocardiography. (r = 0.6-0.8) There was no significant correlation when comparing pre- and post-contrast expiratory CT protocol and echocardiography, and the mean PV/PA value was also significantly different. The absence of correlation between the PV/PA values measured by expiratory CT protocol and echocardiography is thought to be due to inconsistent changes in the diameters of PV and PA during expiration. Respiratory phase was not considered when measuring PV/PA obtained from echocardiography, whereas from expiratory CT protocol, respiratory movement was completely restricted to obtain PV/PA measurement. Therefore, it may have made a difference in the mean PV/PA value between the two modalities. As mentioned earlier, other consideration for the difference in ratios between modalities is may be caused by different angles creating the sections used to measure the vessel diameters. Each cross-section obtained from different angles in CT and echocardiography may cause changes in the overall diameter of the measured PVs and PAs.

Variability within and between observers in PV and PA measurements in CT and echocardiography was favorable, as demonstrated by low mean coefficient of variation. Despite difficulties in determining the boundaries between vessels in pre-contrast CT images, this repeatability of measurements in all protocols, including pre- and post-contrast, implies that contrast is not essentially required to evaluate PV and PA size.

One of the limitations of this study is that the presence of PH could not be clearly excluded because direct measurement of pulmonary arterial pressure was not made through pulmonary artery catheterization, and TR and PR measurements were not possible in all dogs. Moreover, since the number of dogs included in this study is small, the calculated PV/PA value is insufficient to be the reference interval basis. Also, as most of the dogs in this study had similar body conformation, it could affect the results when more diverse group of breeds and conformations were targeted. In this study, CT scan was not performed with electrocardiographic gating. A previous study showed that PV/PA had similar values in both systolic and diastolic conditions in normal dogs (Birettoni et al., 2016), also the use of gating for routine clinical measurements is impractical and therefore not considered in this study. However, PV/AO and PA/AO values differed according to the phase of the cardiac cycle in the previous study, and since it has not been studied about the change in PV/PA values according to the cardiac cycle in dogs with related diseases, further research is needed.

Conclusion

In this study, PV/PA, a new indicator previously proposed in echocardiography, was measured similarly by using CT and obtained similar values in the inspiratory CT protocols. In diagnosing PH, CT evaluation can be suggested as a useful diagnostic guide as it can identify abnormalities in both cardiovascular and pulmonary structures, and more information can be obtained if the changes in related blood vessels, such as PV and PA, are evaluated together. However, the respiratory cycle had a significant effect on the PV/PA value measured by CT, which must be considered when evaluating pulmonary vascular size through CT. A further study on comparing PV/PA value of diseased models and control models is needed in order to determine the normal cutoff PV/PA value using CT.

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국문초록

건강한 개에서 폐정맥 대 폐동맥 비율의 컴퓨터 단층 촬영 측정: 호흡 주기 및 조영 검사의 영향

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수의학에서 폐고혈압의 진단은 도플러 심장초음파를 통한 삼첨판 및 폐동맥 역류 속도 측정에 의존한다. 하지만 이는 항상 가능하지는 않으며, 정확하지 않을 수 있기 때문에 대체할 수 있는 심장초음파 지표들이 연구되어왔다. 최근에 심장초음파를 통해 제안된 폐정맥 대 폐동맥 비율은 건강한 개에서 약 1로 알려졌으나, 아직까지 컴퓨터 단층 촬영을 이용한 측정은 이루어지지 않았다. 본 연구의 목적은 건강한 개의 흉부 컴퓨터 단층 촬영으로 얻은 폐정맥 대 폐동맥 비율을 이전 연구에서 심장초음파로 얻은 값과 비교하고, 컴퓨터 단층 촬영을 통한 폐정맥 대 폐동맥 비율의 측정이 반복 가능하고 재현 가능한지 확인하고, 측정된 폐정맥 대 폐동맥 비율에 대한 조영 및 호흡 단계의 영향을 평가하는 것이다.

폐고혈압이 없는 것으로 간주되는 10마리의 건강한 개를 마취하여 조영 전 흡기, 조영 전 호기, 조영 후 흡기, 조영 후 호기의 4가지 서로 다른 프로토콜을 이용한 흉부 컴퓨터 단층 촬영 및 심장초음파를 실행했다. 폐정맥 대 폐동맥 비율은 각 컴퓨터 단층 촬영 프로토콜에 대해 세 명의 관찰자가 각각 세 번 측정하고 심장초음파에서 얻은 측정값과 비교했다. 흡기 시 촬영한 컴퓨터 단층 촬영 영상에서 얻은 평균 폐정맥 대 폐동맥 비율은 조영 전과 조영 후 모두 1에 가까웠으며, 이는 이미 알려진 심장초음파 값과 유사했다. 흡기 프로토콜 영상과 호기 프로토콜 영상 간에 평균 폐정맥 대 폐동맥 비율의 유의미한 차이가 확인되었으며 (P < 0.001) 호기 프로토콜 영상에서 더 높은 값으로 나타났다 (P < 0.001). 조영 전후 흡기 프로토콜 영상과 심장초음파에서 얻은 폐정맥 대 폐동맥 비율은 통계적으로 유의한 선형 관계가 확인되었다 (r > 0.5, P < 0.05). 조영 전후 호기 프로토콜 영상과 심장초음파에서 얻은 폐정맥 대 폐동맥 비율 사이에는 선형 관계가 관찰되지 않았다. 결론적으로 흉부 컴퓨터 단층 촬영을 통해 심장초음파와 유사한 방식으로 폐정맥 대 폐동맥 비율의 측정이 가능하며 흡기 시 컴퓨터 단층 촬영으로 측정한 폐정맥 대 폐동맥 비율은 심장초음파로 측정한 값과 유사하였다. 하지만 호기 시에는 기존에 알려진 값과 차이가 있어 컴퓨터 단층 촬영을 통해 폐혈관 크기를 평가할 때에는 호흡 단계를 고려해야 할 것이다.

주요어: 심혈관계 질환, 심장초음파, 폐고혈압, 지표, 개

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